

# **Dynamic Properties of Municipal Solid Waste Landfills for Site Response Analyses**

1434-HQ-97-GR-03093

Glenn J. Rix  
Georgia Institute of Technology  
School of Civil and Environmental Engineering  
Atlanta, GA 30332-0355  
Phone: (404) 894-2292  
Fax: (404) 894-2281  
E-mail: glenn.rix@ce.gatech.edu

Program Element: II - PT

Keywords: Wave propagation, site effects, amplification

## **Introduction**

In recent years the presence of municipal solid waste landfills (MSW) in the vicinity of highly populated urban areas has significantly increased the environmental hazard associated with an earthquake-induced failure of an MSW landfill. A critical component in the design of a new MSW landfill is the assessment of its stability under prescribed earthquake loadings. The seismic stability of both new and old MSW landfills is often the governing factor of the overall design of these facilities, particularly when planar geosynthetic components are used in the landfill. Despite the importance of seismic concerns in the design of MSW landfills, very limited information is currently available regarding the small-strain dynamic properties of municipal solid waste (i.e. the initial tangent shear modulus,  $G_{\max}$ , and the small-strain shear hysteretic damping ratio,  $D_s$ ). The lack of data on hysteretic damping ratio is particularly acute.

In this study we have developed a methodology for simultaneously determining the shear wave velocity and the shear hysteretic damping ratio of municipal solid waste using surface waves. Thus far, the new procedure has been successfully applied at two MSW landfills with varying waste composition and age. The use of surface wave tests to determine the small-strain dynamic properties of a site has several advantages over more conventional methods such as cross-hole and down-hole tests. The attractive feature of surface wave tests is that they are non-invasive, and hence do not require the use of boreholes and probes. At MSW landfills, non-invasive tests such as surface wave tests are an excellent choice for an in-situ investigation program because they do not require any penetration into the subsurface which could compromise the liner systems.

## Investigations Undertaken

In active surface wave measurements, the experimental dispersion curve, which shows the frequency dependence of surface (Rayleigh) wave velocity, is calculated from measurements of phase differences  $\theta(\omega)$  between two receivers separated by a known distance  $\Delta r$ . Determination of the small-strain shear damping ratio profile requires measurements of the spatial attenuation coefficient of harmonic Rayleigh waves. The experimental attenuation curve is a plot showing the spatial attenuation coefficient as a function of frequency. The experimental Rayleigh wave attenuation coefficients  $\alpha_R(\omega)$  are obtained from measurements of the vertical particle displacement spectra,  $|w(r, \omega)|$ , at several receiver offsets. To improve the accuracy of the experimental attenuation data, the particle velocity spectrum measured at each receiver location is corrected to reduce the adverse effects of ambient noise.

Once the experimental dispersion and attenuation curves have been computed, an inversion algorithm must be employed to back-calculate the corresponding shear wave velocity and shear damping ratio profiles. This inverse problem can be solved in either a coupled or uncoupled formulation. The coupled inversion consists of simultaneously determining both the shear wave velocity and shear damping ratio profiles from experimental surface wave velocity and attenuation measurements. It is superior to the uncoupled inversion not only because it is more consistent with the physics of the problem (i.e., the two aspects are inherently coupled), but also because the simultaneous inversion constitutes a better posed problem from the mathematical point of view (Rix and Lai, 1998; Lai, 1998). In the coupled formulation, the medium (i.e., the MSW landfill) is assumed to behave as a viscoelastic material characterized by complex-valued seismic velocities.

The surface wave velocity and attenuation measurement techniques described above are appropriate for tests performed at the free surface of a vertically heterogeneous half-space. Wave propagation phenomena in media that are laterally bounded such as landfills are expected to be different from those of a half-space. Sykora (1995) has shown that for velocity measurements, boundary effects in embankments are generally negligible. However, this conclusion may not be appropriate for attenuation measurements, which could be altered by interference among seismic waves induced by the presence of the boundaries. In this case the procedure should be modified in order to calculate the experimental attenuation coefficients  $\alpha_R(\omega)$  accurately. A parametric study using a finite element program (ABAQUS) was performed to evaluate the importance of these phenomena. The following section describes the results of this parametric study.

Surface waves tests were performed at two MSW landfills sites. Both the landfills are located in the metro Atlanta, Georgia area. The waste placement techniques at the two landfills vary. The difference in the techniques is mostly due to the use of soil as daily cover over the waste. Older landfilling techniques typically used more soil than newer methods. The age of the waste will determine the extent of the compression the waste has undergone. Older waste yields higher densities due to more time compressed under its own weight.

The first MSW landfill that was tested is owned by Sanifill, Inc. and is located approximately 16 km northwest of downtown Atlanta, Georgia. The placement dates of the waste tested range from the mid 1980's to 1993. Unfortunately, very little information for this landfill is available. It is believed that a 50 to 60 cm thick soil layer overlies a geosynthetic and clay composite layer.

Under this composite layer is a 30-cm thick layer of soil, followed by 2.5 m of sludge from a wastewater treatment plant, followed by the MSW (R. Howell, personal communication). The waste at this landfill is classified as "old waste" because 15 cm of daily soil cover was used. This soil was not removed prior to further waste placement.

The second MSW landfill is the Bolton Road Sanitary Landfill operated by USA Waste Services Inc. located adjacent to the Sanifill landfill. The placement dates of the waste tested range from 1994 to 1996. The landfill covers approximately 20.23 ha. Each of five lifts ranges in height from 3.1 to 4.6 m and adjacent lifts are separated by an intermediate soil cover layer which is between 30 to 60 cm thick. The overall waste height ranges from approximately 21 to 24 m. The waste at this landfill is classified as "new waste" because a temporary "polytarp" cover is placed over the waste instead of daily soil cover (D. Cieply, personal communication).

## Results

The non-linear inversion algorithm described above has been used to simultaneously determine the shear wave velocity and shear damping ratio profiles using the experimental dispersion and attenuation curves of Bolton Road and Sanifill MSW landfills. Figure 1(a) and Figure 2(a) illustrate the convergence of the algorithm for both sites by comparing the experimental and the theoretical dispersion and attenuation curves as the number of iterations progresses. The corresponding sequences of shear wave velocity and shear damping ratio profiles are shown in Figure 1(b) and Figure 2(b), where the dashed lines indicate the starting models used in the inversion. The shear wave velocity and shear damping ratio profiles of the last iteration are shown

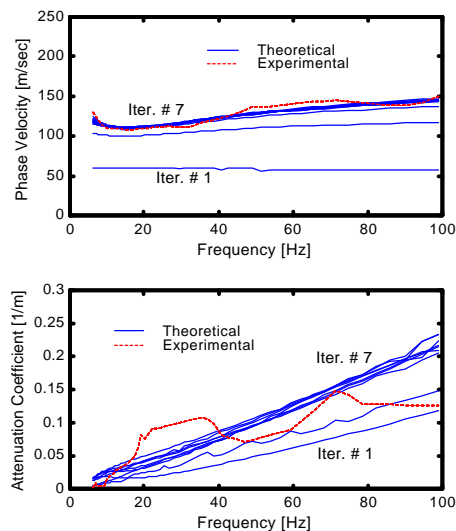


Figure 1(a) Experimental and Theoretical Dispersion and Attenuation Curves at Bolton MSW Landfill

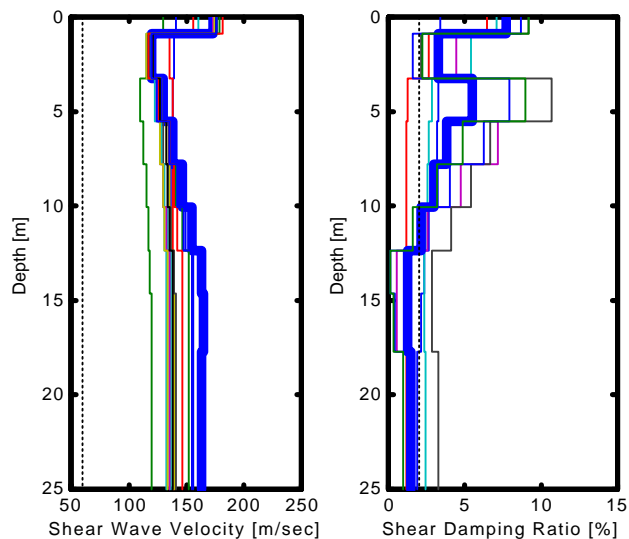


Figure 1(b) Shear Wave Velocity and Shear Damping Ratio Profiles at Bolton MSW Landfill

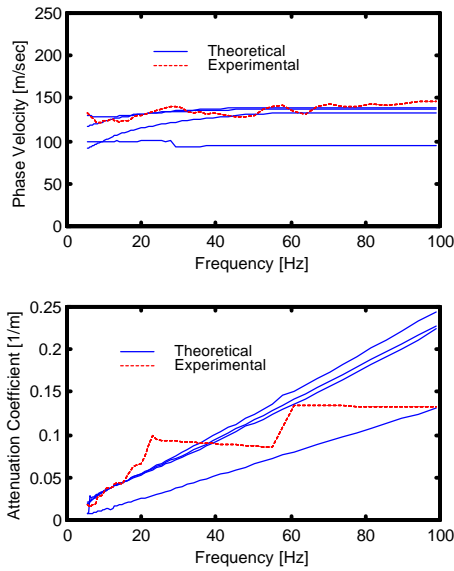


Figure 2(a) Experimental and Theoretical Dispersion and Attenuation Curves at Sanifill MSW Landfill

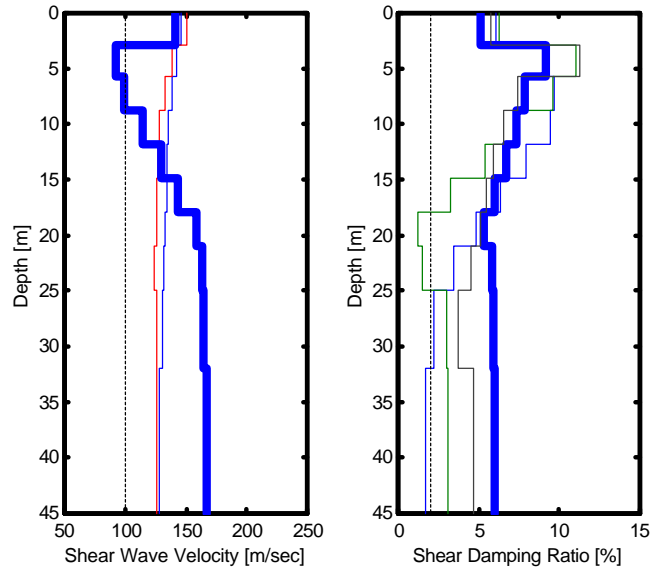


Figure 2(b) Shear Wave Velocity and Shear Damping Ratio Profiles at Sanifill MSW Landfill

as bold lines. In both cases, the experimental and theoretical dispersion curves match very well. The agreement between experimental and theoretical attenuation curves is less satisfactory, reflecting the difficulty of making accurate material attenuation measurements due to the superposition of material and geometric attenuation.

For both landfills, the presence of the stiffer compacted soil cap overlying the waste is properly captured. The velocity of the MSW increases with depth from approximately 100 to 160 m/sec. The shear damping ratio profile at the Bolton Road landfill varies from 1% to 7% whereas for the Sanifill landfill the variation of  $D_s$  with depth is from 5% to 9%. In general, the values of  $D_s$

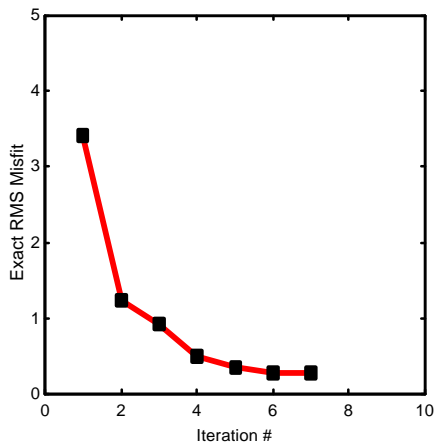


Figure 3(a) RMS Misfit Vs Iteration Number at Bolton MSW Landfill

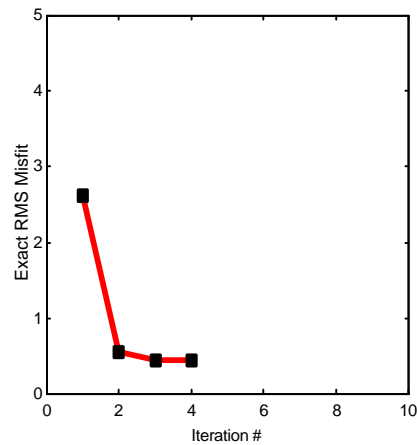


Figure 3(b) RMS Misfit Vs Iteration Number at Sanifill MSW Landfill

decrease with depth. Finally, Figure 3 illustrates the convergence of the algorithm in terms of the root-mean-square (rms) error between the experimental and theoretical complex-valued phase velocities; seven and four iterations were required for the algorithm to converge for the Bolton Road and Sanifill sites, respectively.

The results indicate that the shear wave velocity profiles are approximately the same for both the Sanifill and Bolton Road MSW landfills, but that the shear damping ratios are substantially less for the Bolton Road landfill. This suggests that the newer waste stream containing less soil may provide lower material damping and thus greater amplification of ground motions than older waste streams with more soil.

### **Non-Technical Summary**

The potential failure of a municipal solid waste (MSW) landfill during an earthquake poses an environmental hazard. Currently, there is limited information on the dynamic properties of the waste material used to assess the response of the landfill to an earthquake. Non-invasive field tests have been performed at two MSW landfills: one older landfill in which the waste is mixed with significant amounts of soil and a newer landfill containing less soil. Results indicate that the stiffness of the two waste streams is similar, but the newer waste does not dissipate as much energy in the form of material damping.

### **Reports Published**

- Haker, C.D., G.J. Rix, and C.G. Lai, "Dynamic Properties of Municipal Solid Waste Landfills from Surface Wave Tests," *Proceedings*, Symposium on the Application of Geophysics to Engineering and Environmental Problems, pp. 301-310, 1997.
- Rix, G. J., C. G. Lai, S. Foti, and D. Zywicki, "Surface Wave Tests in Landfills and Embankments," *Geotechnical Earthquake Engineering and Soil Dynamics III*, ASCE Geotechnical Special Publication No. 75, Dakoulas, P., Yegian, M., and Holtz, R.D., Eds., pp. 1008-1019, 1998.
- Rix, G. J., and C. G. Lai, "Simultaneous Inversion of Surface Wave Velocity and Attenuation," *Geotechnical Site Characterization*, P.K. Robertson and P.W. Mayne, Eds., Balkema, Rotterdam, pp. 503-508, 1998.
- Lai, C.G., and G. J. Rix, "Simultaneous Inversion of Rayleigh Phase Velocity and Attenuation for Near-Surface Site Characterization," Report No. GIT-CEE/GEO-98-2, Georgia Institute of Technology, School of Civil and Environmental Engineering, 258 pp. 1998.

### **Availability of Data**

Surface wave velocity and attenuation data is available in Hewlett-Packard Standard Data Format (SDF) or Matlab mat-files from Dr. Glenn J. Rix at 404-894-2292 or [glenn.rix@ce.gatech.edu](mailto:glenn.rix@ce.gatech.edu).